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SIMULTANEOUS MEASUREMENTS OF THE AURORAL IONOSPHERE BY THE CHAT--ETC(U)

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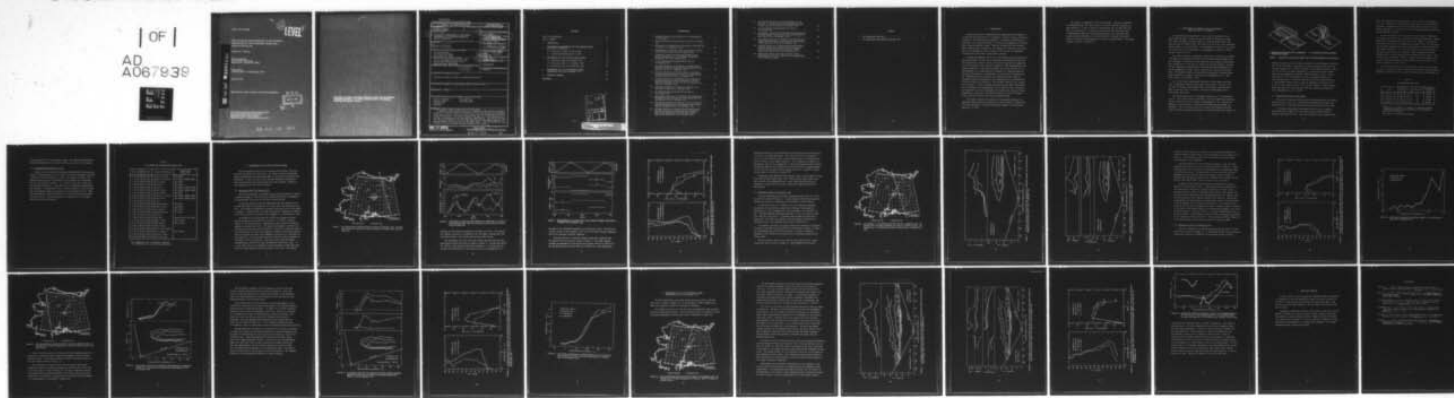
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**SIMULTANEOUS MEASUREMENTS OF THE AURORAL
IONOSPHERE BY THE CHATANIKA RADAR AND
THE S3-2 SATELLITE**

Richard R. Vondrak

SRI International
333 Ravenswood Avenue
Menlo Park, California 94025

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1. INTRODUCTION

A major objective in understanding the geophysical environment is to identify the distribution of ionization, electric fields, and electric currents in the high-latitude ionosphere. The spatial distribution of ionization is of interest because it affects the propagation of HF radio waves along transauroral paths. Electric currents can heat the atmosphere through joule dissipation, and change the orientation and intensity of the geomagnetic field, and may be the source of ionospheric irregularities that affect communication systems.

Although many general features of the high-latitude ionosphere have been established, we have only a rudimentary understanding of how the electron density, electric field, and electric currents are organized as a total system and how they are related to other magnetospheric and auroral parameters. This report presents the initial results of an investigation of the high-latitude ionosphere by comparing radar and satellite observations. Measurements of the electrical properties of the ionosphere have been made by the incoherent-scatter radar at Chatanika, Alaska simultaneously with measurements by instrumentation on the Air Force S3-2 satellite. The ultimate objective of a coordinated analysis of these simultaneous satellite and radar measurements is to reconstruct the configuration of the electric field, currents, and conductivity at high latitudes and to deduce the pattern of these parameters in relation to ionospheric features such as the diffuse aurora, discrete auroral arcs, and the plasma trough.

This report presents the analysis of measurements made by the Chatanika radar during four passes by the S3-2 satellite. These data sets were selected as the most interesting examples of simultaneous data prior to 1978.

The report is organized in the following way. Section 2 describes the Chatanika radar, the data used in this study, and the rationale for data selection. A list is given of measurements made in 1978 that have not yet been analyzed. In Section 3 we describe the three data sets of measurements made when the equatorward edge of the evening diffuse aurora was near Chatanika. The fourth data set is shown in Section 4. This set consists of measurements of an active morning aurora. Concluding remarks are given in Section 5.

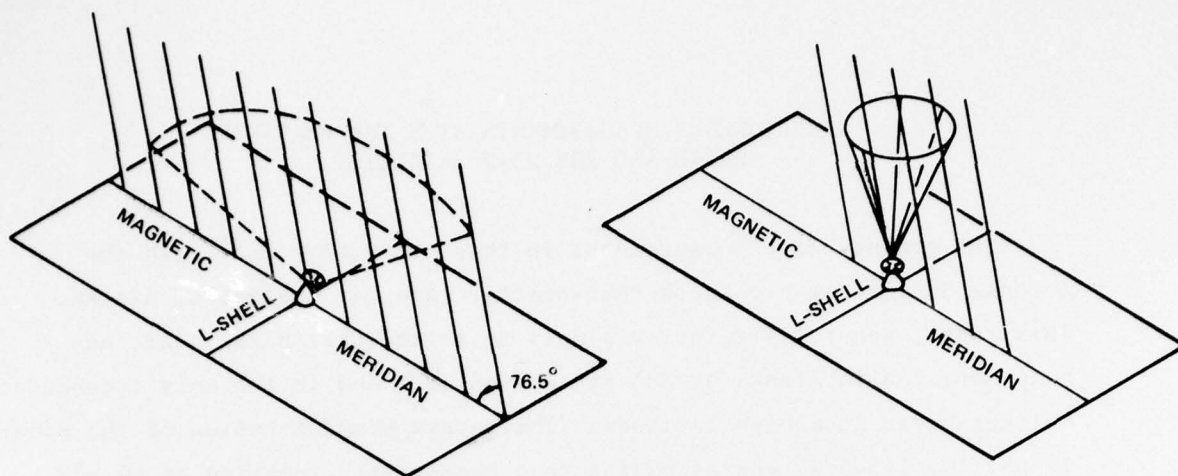
2. SIMULTANEOUS MEASUREMENTS WITH THE CHATANIKA RADAR AND THE S3-2 SATELLITE

The ground-based measurements in this study were made with the Defense Nuclear Agency incoherent-scatter radar at Chatanika, Alaska. This radar, generally referred simply to as the Chatanika radar, has been operated in Alaska by SRI since June 1971 and is the only incoherent-scatter radar at a high latitude. The geographical location of the radar is 65.1°N , 145.5°W , corresponding to a geomagnetic location of 64.9°N , 103.3°W , and an L of 5.7.

The radar transmits a high-power (typically 3.5 MW) pulse of L-band (1290 MHz) electromagnetic radiation and the backscattered signal from the ionosphere is analyzed for both amplitude and frequency distribution. This information is then used to compute the electron density, electron and ion temperature, plasma drift, and other derivable parameters such as the ionospheric electric field, conductivity, current, and neutral wind. The Chatanika radar and associated data-analysis techniques have been described in a number of publications (Leadabrand et al., 1972; Baron, 1974, 1977; Wickwar, 1975).

All of the radar measurements described in this report were made with a transmitted waveform consisting of two pulses. A $67\text{-}\mu\text{s}$ pulse was used for density measurements with a 10-km range resolution and a $320\text{-}\mu\text{s}$ pulse was used for velocity and density measurements with a 48-km range resolution.

The Chatanika radar has a high-gain antenna with a 3-dB beamwidth of 0.5° . As a result, when the antenna is held stationary the horizontal spatial resolution in the E region is approximately 1 km. Because the antenna is fully steerable, a variety of antenna operating modes are employed. All of the scan data in this report were obtained with the radar in either an azimuth-scan mode or an elevation-scan mode (Figure 1).



(a) CONTINUOUS ELEVATION SCAN IN THE GEOMAGNETIC MERIDIAN PLAN (ELSCAN)

(b) CONTINUOUS AZIMUTH SCAN (AZSCAN)

FIGURE 1 CHATANIKA ANTENNA SCAN MODES USED FOR MEASUREMENTS IN THIS REPORT.

During an azimuth scan, the radar is pointed at some elevation, typically 60° to 70° , and then is repetitively scanned in azimuth with about six minutes required for a complete rotation. An alternative mode of operation is to scan the radar mechanically in elevation with the azimuth fixed in the geomagnetic meridian (Vondrak and Baron, 1976). Such a scan results in the determination of the latitudinal variation of measured quantities. Elevation scans made from the northern horizon to the southern horizon cover a range in geomagnetic latitude of 62° to 68° in the E region and 56° to 73° in the F region. Vector measurements are made in an elevation scan with the technique described by de la Beaujardiere, et al. (1977).

2.1 Selection of Data for This Study

This study is based on data selected from Chatanika and S3-2 observations prior to June, 1977. Satellite measurements made after that date have not yet been analyzed and were not available for this study.

To identify simultaneous Chatanika/S3-2 data sets, a computer search was made by AFGL of all S3-2 data passes recorded between December 1975 and June 1977. This search selected those passes during

which the satellite had recorded data in the vicinity of Chatanika-- i.e., the satellite at closest approach was above the local horizon at Chatanika. Depending on satellite altitude, this resulted in a geographic separation of typically less than 1000 km between the satellite groundtrack and the radar.

At SRI this search list was compared to the times of Chatanika measurements recorded in the logbooks of Chatanika operations. Approximately 100 simultaneous data sets were found. Maps of the satellite groundtrack with respect to Chatanika were made for all of these sets, and the radar logbooks were used to determine the radar operating mode and auroral conditions. From the total data set, we then selected satellite passes that were reasonably close to Chatanika and that coincided with a radar operating mode suitable for this study. This revised list was brought to AFGL to compare with the library of S3-2 electric-field measurements, and four passes were selected for comparative analysis in this project.

The selected passes are listed in Table 1, which gives the date and time of closest approach to Chatanika, satellite revolution number, geographic separation of the satellite groundtrack from Chatanika, and

Table 1

S3-2/CHATANIKA DATA SETS

Date	Time (UT)	Rev	Separation*	Chatanika Mode [†]
25 January 1976	0741	708	10°E	AZSCAN
17 February 1976	0728	1031	5°E	ELSCAN
25 February 1976	0817	1144	8°W	ELSCAN
24 February 1977	1509	6352	2°W	ELSCAN

* Separation is distance in degrees of longitude between Chatanika and satellite groundtrack at the geomagnetic latitude of Chatanika.

[†] See text for definitions of modes.

the operating mode of the Chatanika radar. The Chatanika measurements during these passes are described in Sections 3 and 4 of this report.

2.2 Coordinated Measurements in 1978

Because very few useful simultaneous Chatanika/S3-2 data sets were found in the measurements prior to June 1977, many experiments were made during the first three months of 1978. From January to March, 1978 Chatanika operations were coordinated with intensive S3-2 operations prior to the satellite reentry. As a result of the joint efforts of SRI and AFGL scientists, a large data set of simultaneous measurements was obtained. To demonstrate this, we show in Table 2 a list of times when the Chatanika radar was operated for close passes by S3-2. AFGL has confirmed that satellite data were collected during the indicated satellite orbits. These measurements are expected to be a valuable data base for future analyses.

Table 2

S3-2/CHATANIKA COORDINATIONS DURING 1978

Date	Time (UT)	ReV	Auroral Conditions	Satellites* (Time, UT)
31 Jan	1000	11387	Dim arc in south	WB (1029)
3 Feb	1020	11433	Bright arc in north	WB (1044); TRIAD (1025)
4 Feb	1000	11448	Arcs in north	WB (0939)
5 Feb	2020	11470	Overhead arc	WB (2039)
6 Feb	1045	11479	Double arc	WB (1058); TRIAD (1034)
7 Feb	1020	11494	Diffuse aurora	WB (0954); TRIAD (1003)
8 Feb	1000	11509	Diffuse aurora	WB (1034)
9 Feb	0930	11524	Bright arc in north	WB (0929); TRIAD (1042)
10 Feb	1035	11540	Multiple arcs	WB (1008); TRIAD (1011)
11 Feb	1010	11555	Dim arc	
1 Mar	1016	11829	Pulsating aurora	WB (1031)
1 Mar	2059	11837	Daytime; active	WB (2051)
2 Mar	1113	11846	Active aurora	WB (1111)
3 Mar	1209	11861	Pulsating aurora	WB (1151)
4 Mar	1132	11877	Very quiet	
5 Mar	1054	11892	Bright arcs	TRIAD (1017); WB (1126)
6 Mar	1148	11908	Dynamic aurora	AE-C (1150)
9 Mar	1122	11951	Bright aurora	AE-C (1132)
11 Mar	0959	11984	Dynamic aurora	
12 Mar	1047	12000	Dense F; no auroral E	
13 Mar	1004	12014	Dense F; small E	AE-C (1029)
18 Mar	1052	12092	Plasma Line Expt.	
20 Mar	1048	12123	Plasma Line Expt.	

* WB = Wideband; AE-C = Atmospheric Explorer;
some TRIAD data may not have been recorded.

3. MEASUREMENTS OF THE EVENING DIFFUSE AURORA

Three simultaneous data sets from January and February 1976 were selected for analysis in this study. All three sets were premidnight passes during which the equatorward edge of the diffuse aurora was near Chatanika. In this section we will describe Chatanika measurements made simultaneously with these passes and, where possible, comment on the comparison with S3-2 satellite data.

3.1 Revolution 708 on 25 January 1976

The S3-2 groundtrack over Alaska during Revolution 708 on 25 January is shown in Figure 2. The satellite crossed the latitude of Chatanika at approximately 0741 UT at an altitude of about 870 km.

During the satellite pass the Chatanika radar was operated in an azimuth scan mode at an elevation of 67° with each scan requiring 6 minutes. The E-region (100-200 km) coverage during each scan is also shown in Figure 2. Azimuth scans were made continuously, beginning at 0600 UT, until 0754 UT when the operations were changed to a three-position mode.

From 0600 UT until approximately 0730 UT the E-region electron density measured at Chatanika was less than $1 \times 10^5/\text{cm}^3$, a density typical of the diffuse aurora. Beginning at about 0730 UT the density gradually increased with time. The spatial and temporal variations of ionization and conductivity from 0730 UT to 0750 UT are shown in Figure 3. In the upper panel is shown the geographic azimuth of the radar pointing direction during the scans; the geomagnetic directions are indicated on the right axis. The lower panel shows the electron density measured at altitudes of 120 km and 200 km. The center panel shows the height-integrated Hall conductivity (Σ_H) and Pedersen conductivity (Σ_P). It is seen that there were substantial spatial gradients during each scan, with the larger densities usually present in the north. The density

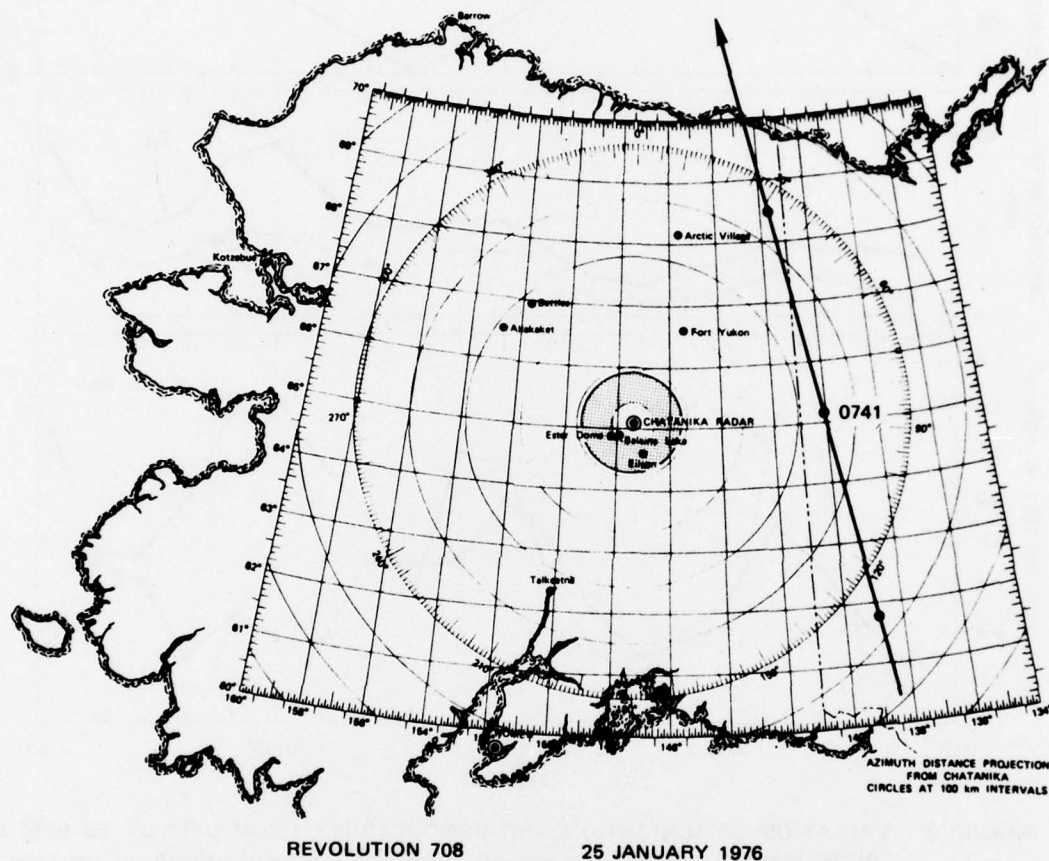


FIGURE 2 S3-2 GROUNDTRACK DURING REVOLUTION 708 ON 25 JANUARY 1976. The shaded region indicates the E-region (100 to 200 km) surveyed by the Chatanika radar during the satellite pass.

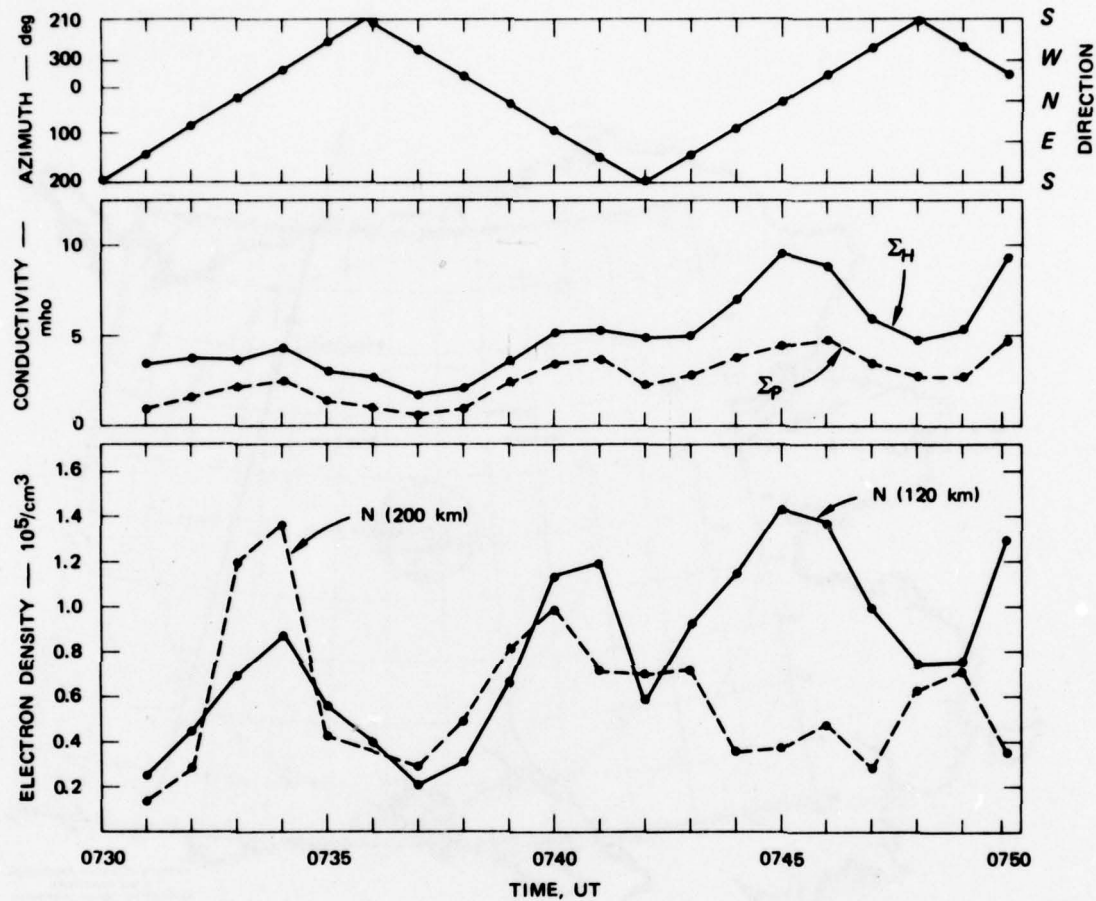


FIGURE 3 VARIATION OF IONIZATION AND CONDUCTIVITY FROM 0730 UT TO 0750 UT ON 25 JANUARY 1976. Upper panel indicates the pointing azimuth of the radar during the measurements.

measured in each direction generally increased with time. This spatial and temporal variation is consistent with the radar crossing under the equatorward edge of the diffuse aurora during this period.

The ionospheric electric field and current derived from the radar measurements during each scan are shown in Figure 4. During this period the electric field pointed toward the northwest. It is seen that the increase of conductivity in the diffuse aurora was accompanied by a

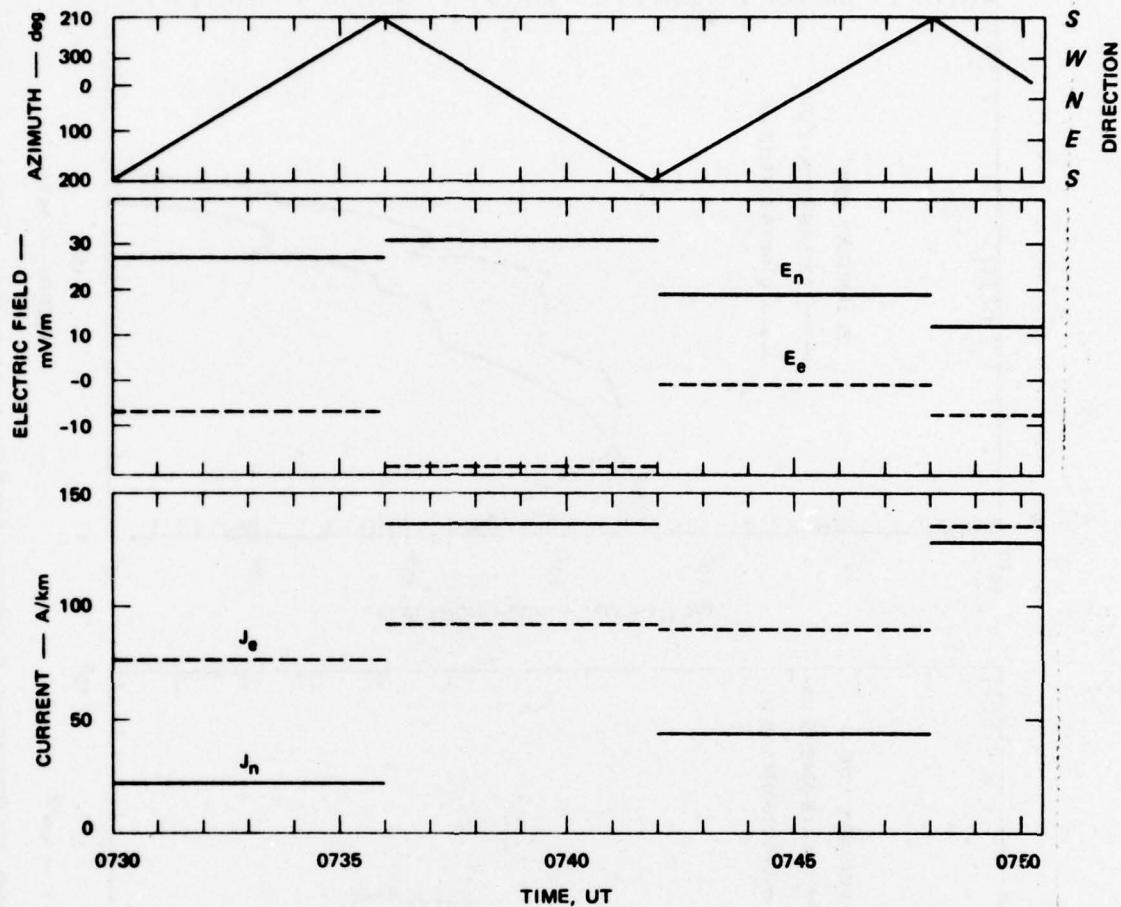


FIGURE 4 MEASUREMENTS OF ELECTRIC FIELD AND ELECTRIC CURRENT FROM 0730 UT TO 0750 UT ON 25 JANUARY 1976

decrease in the northward component of the electric field. The electric current flowed to the northeast, with a fairly uniform eastward component and a more variable northward component.

Altitude profiles of electron density during two intervals near the time of the S3-2 pass are shown in Figure 5. The radar scanned through the geomagnetic south during the interval 0741:18 to 0742:12 UT and through the north during 0746:16 to 0745:18 UT. The differential

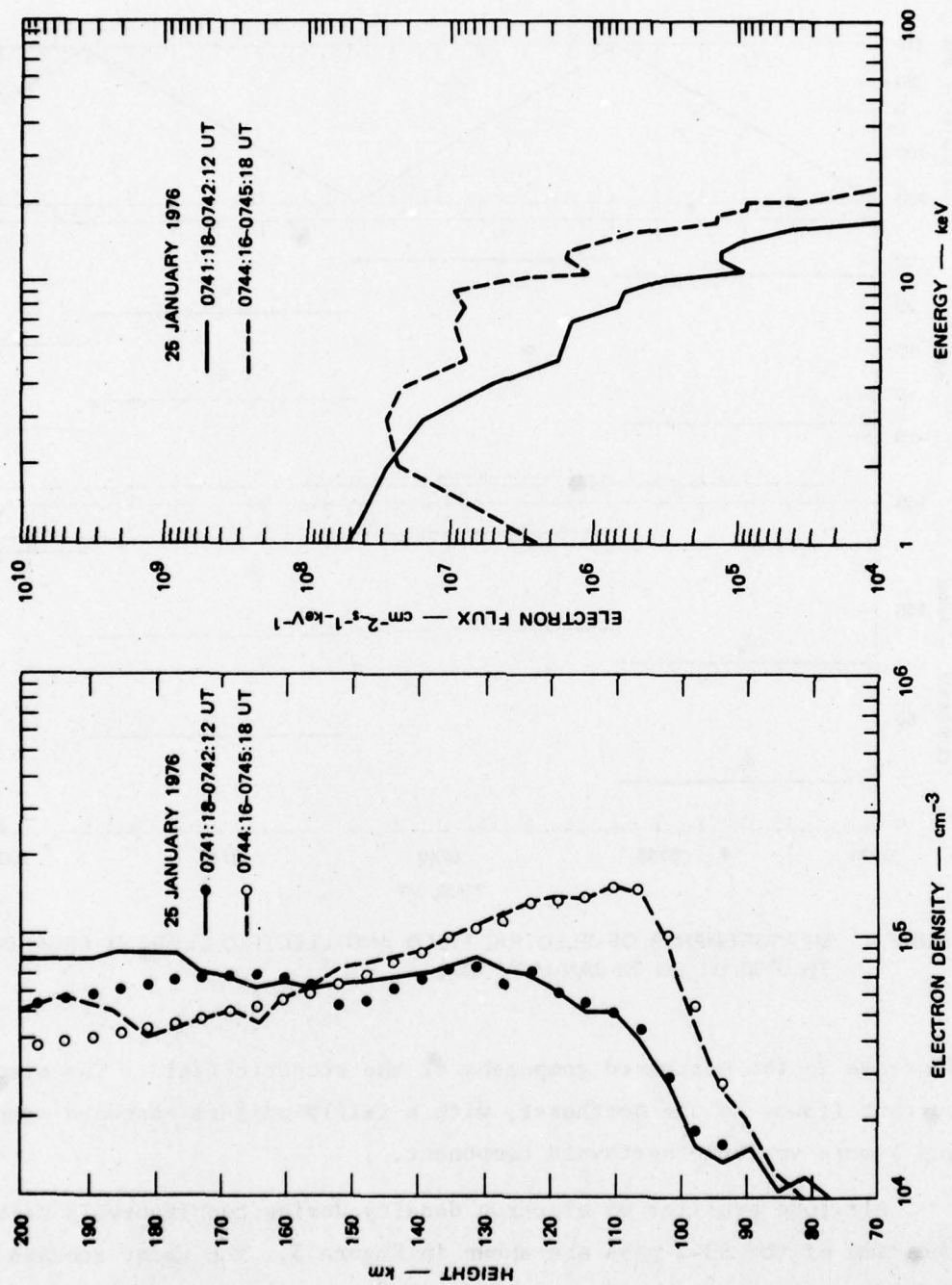


FIGURE 5 IONIZATION PROFILES AND PRECIPITATING ELECTRON ENERGY DISTRIBUTION AT TWO AZIMUTHS DURING S3-2 REVOLUTION 708 ON 25 JANUARY 1976

energy distribution of precipitating electrons inferred from each profile is shown in the right-hand panel. The altitude profile of ionization that would be produced by these energy distributions is indicated by the points overlaid on the density profiles. This comparison is shown as a consistency check on the computation of the precipitating electron fluxes. The spatial gradient in ionization and electron fluxes is quite apparent. In the north the incoming electron energy flux was $1.1 \text{ erg/cm}^2\text{-s}$, while in the south it was about $0.4 \text{ erg/cm}^2\text{-s}$.

Preliminary S3-2 satellite data indicate that a field-aligned current sheet and the equatorward edge of the diffuse aurora were present near the latitude of the Chatanika radar. When final satellite data are available, a comparison can be made between the radar and satellite measurements.

3.2 Revolution 1031 on 17 February 1976

The S3-2 groundtrack over Alaska during Revolution 1031 on 17 February 1976 is shown in Figure 6. At approximately 0728 UT the satellite crossed the latitude of Chatanika at an altitude of about 280 km.

During the evening of 17 February 1976 the radar was generally operated in an elevation scan mode with occasional fixed-position measurements to the northeast and to the northwest at an elevation of 60° . The last complete elevation scan prior to the S3-2 pass was made from 0701:28 to 0716:34 UT. A partial scan was made from 0716:39 to 0721:06 UT. The radar was pointed to the northeast from 0722:36 to 0728:26 UT and to the northwest from 0731:37 to 0736:37 UT.

The spatial variation of electron density and conductivity measured during the elevation scan from 0701:28 to 0716:34 UT is shown in Figure 7. The equatorward edge of the diffuse aurora is visible overhead at Chatanika, with ionization and conductivity increasing at greater distances north.

The latitudinal variation of electric field and electric current during this scan is shown in Figure 8. These parameters were also

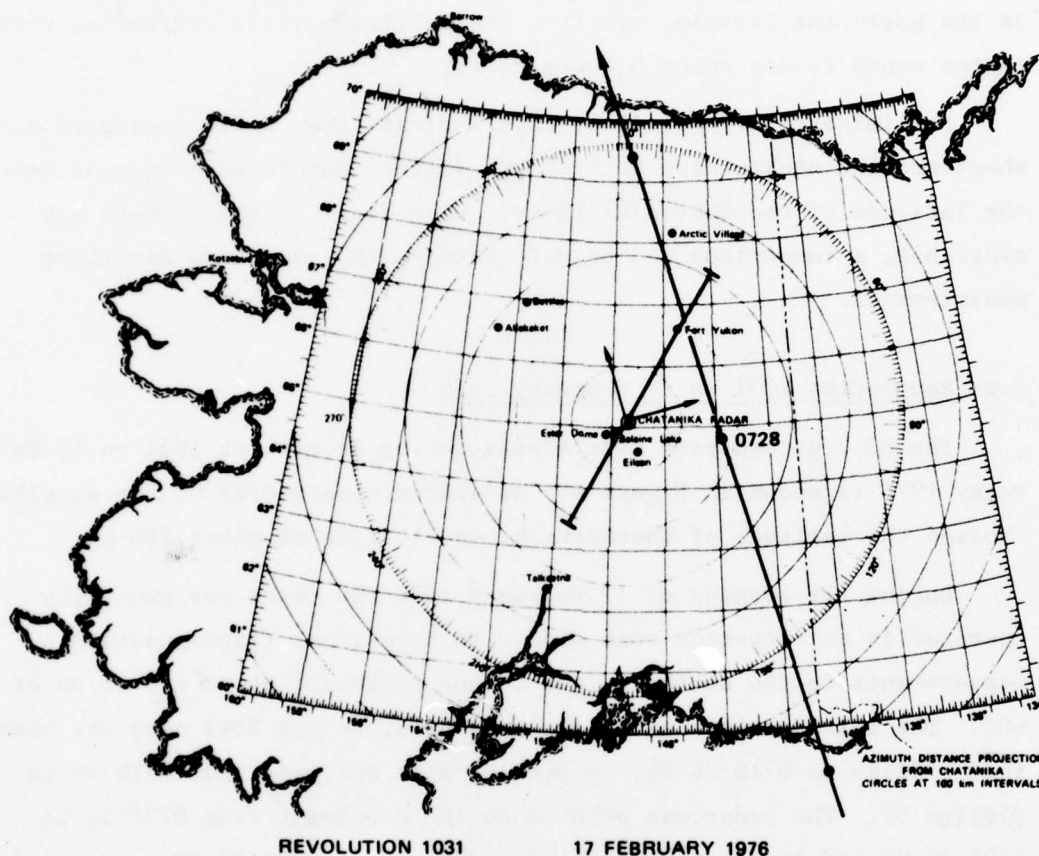


FIGURE 6 S3-2 GROUNDTRACK DURING REVOLUTION 1031 ON 17 FEBRUARY 1976. The latitudinal extent of E-region measurements at an altitude of 100 km is shown by the heavy solid line. Also indicated are the pointing directions while in the fixed-position mode.

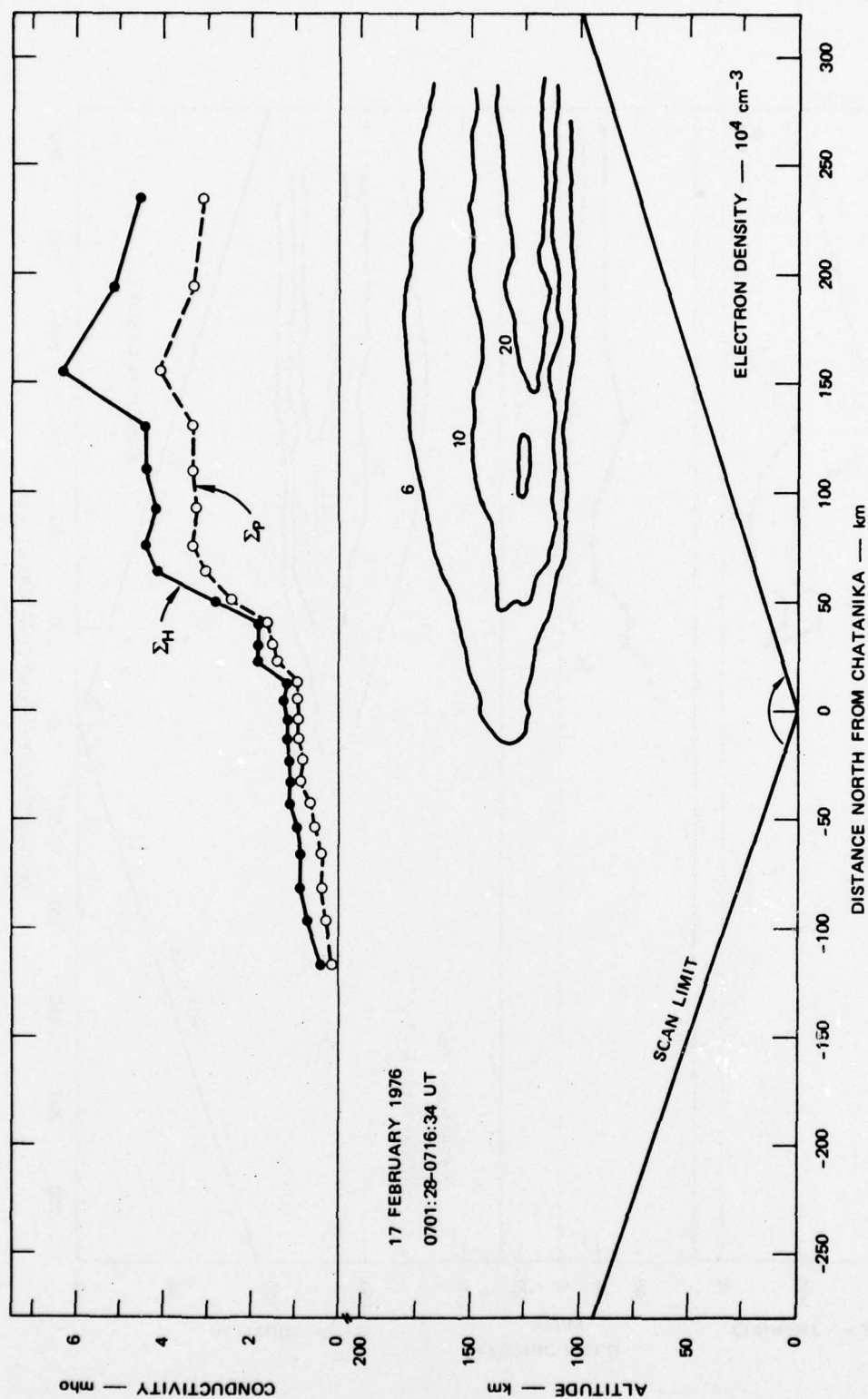


FIGURE 7 LATITUDE VARIATION OF IONIZATION AND CONDUCTIVITY MEASURED DURING THE ELEVATION SCAN BETWEEN 0701:28 AND 0716:34 UT ON 17 FEBRUARY 1976

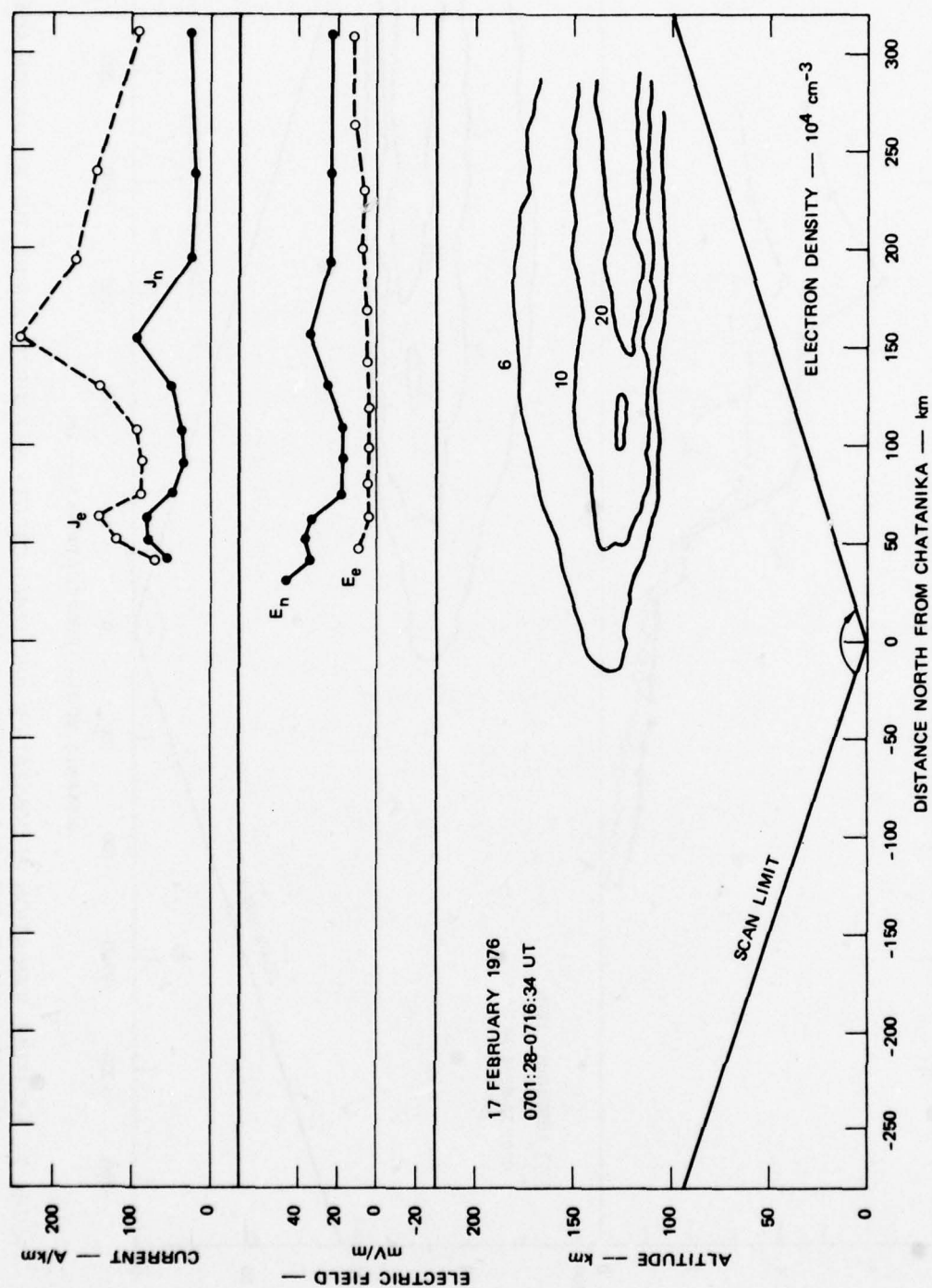


FIGURE 8 LATITUDE VARIATION OF ELECTRIC FIELD AND ELECTRIC CURRENT MEASURED DURING THE ELEVATION SCAN BETWEEN 0701:28 AND 0716:34 UT ON 17 FEBRUARY 1976

measured in the trough to the south, but a more detailed analysis is required before accurate values can be determined in this region of low density. In the diffuse aurora both the electric field and current were directed to the northeast.

Altitude profiles of electron density measured in the two fixed positions near the time of the S3-2 pass are shown in Figure 9. These pointing directions correspond to measurements in the equatorward edge of the diffuse aurora. The similarity of the two profiles and their agreement with the earlier density measurements shown in Figure 7 indicate that the spatial location and intensity of the diffuse aurora did not vary significantly during the time of the S3-2 pass.

In Figure 10 are shown the latitudinal variations of electron density at an altitude of 290 km. These densities were measured with the 320- μ s pulse, which has a spatial resolution of 48 km. These densities (and all other electron densities shown in this report) were derived from the radar data with the assumption that the electron cross section is equal to the classical Thomson cross section. This result is generally not exact because the radar cross section of the electrons is not a constant; due to plasma interactions it is a function of the electron and ion kinetic temperatures, and to a smaller extent a function of the ratio of the Debye length to the operating wavelength. The effect of neglecting this correction factor is to always underestimate the true electron density. This plasma correction factor is generally negligible in the E-region (<150 km altitude). At an altitude of 290 km (Figure 10) in the quiet aurora, the correction could be as large as 100%.

3.3 Revolution 1144 on 25 February 1976

The S3-2 groundtrack over Alaska during Revolution 1144 on 25 February 1976 is shown in Figure 11. At approximately 0817 UT the satellite crossed the latitude of Chatanika at an altitude of about 240 km.

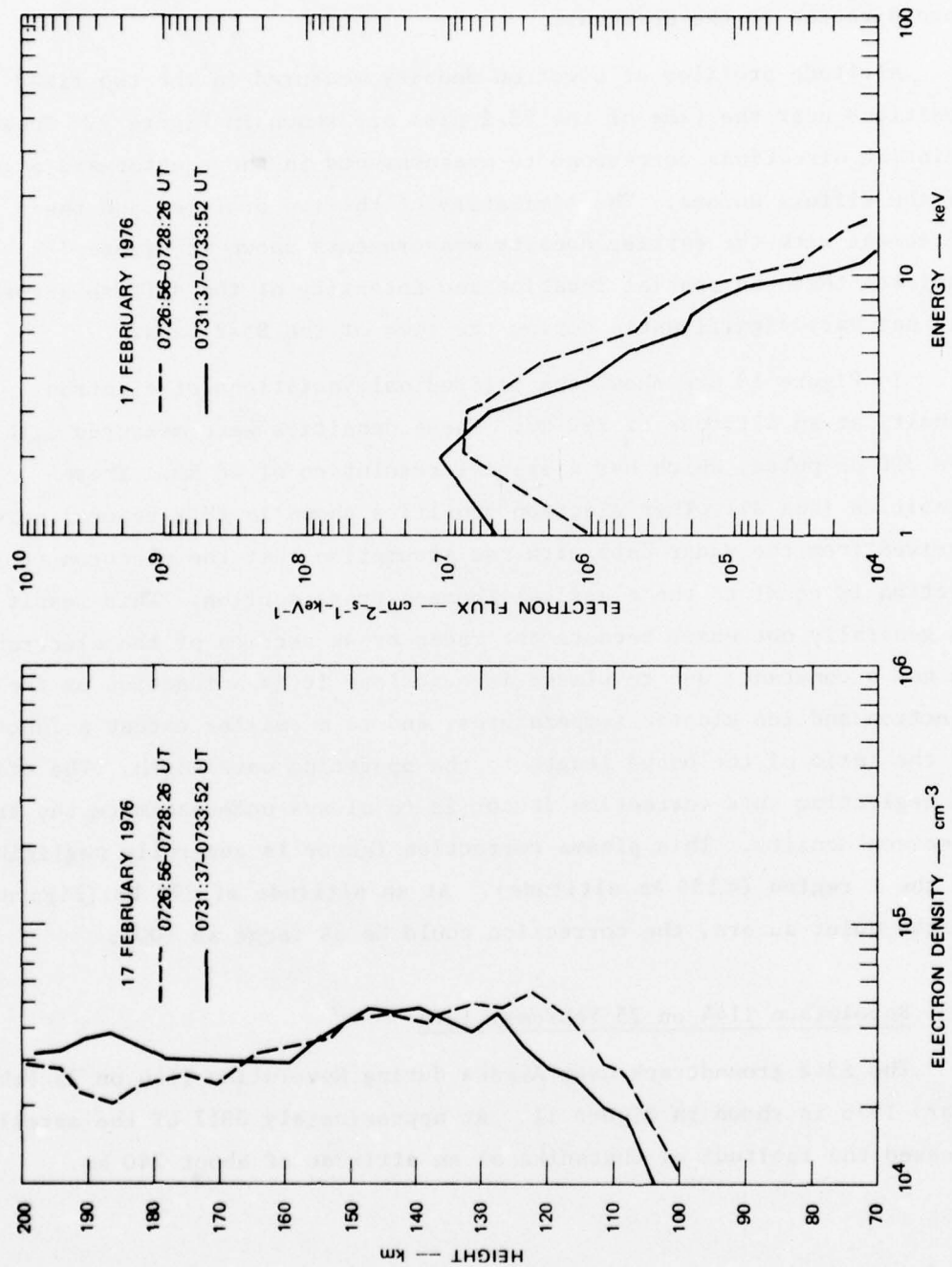


FIGURE 9 ALTITUDE PROFILES OF IONIZATION AND PRECIPITATING ELECTRON ENERGY DISTRIBUTION MEASURED IN FIXED-POSITION MODE NEAR THE TIME OF THE S3-2 REVOLUTION 1031 ON 17 FEBRUARY 1976

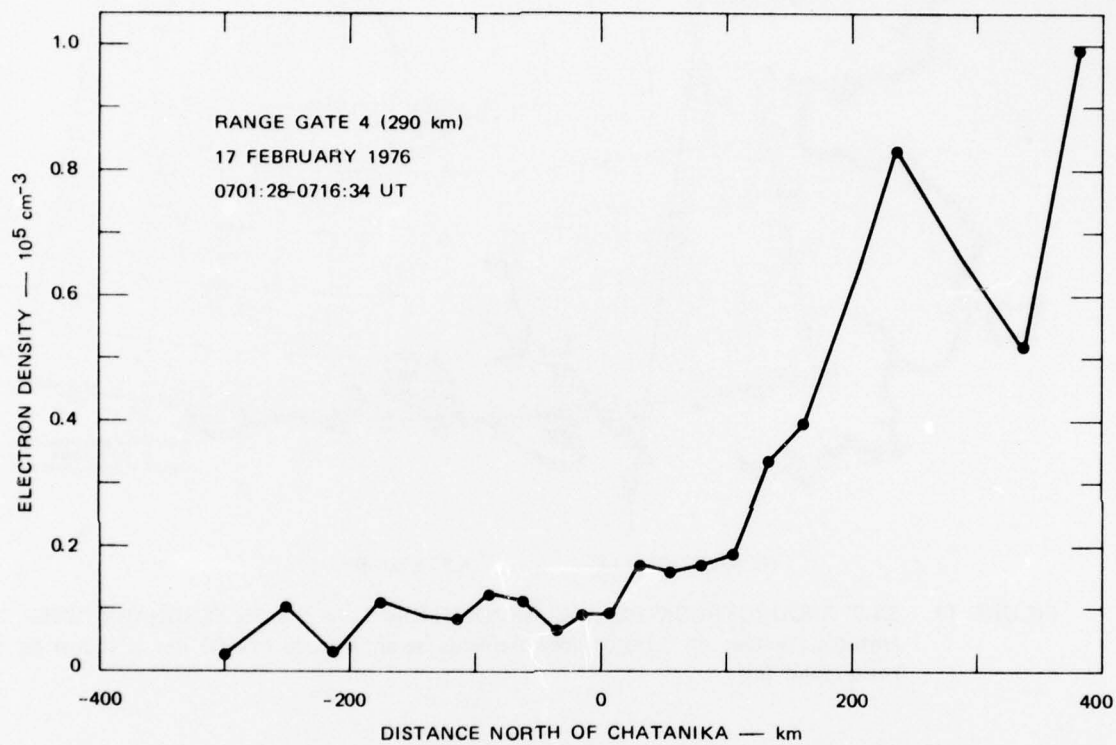


FIGURE 10 LATITUDINAL VARIATION IN ELECTRON DENSITY AT AN ALTITUDE OF 290 km ON 17 FEBRUARY 1976

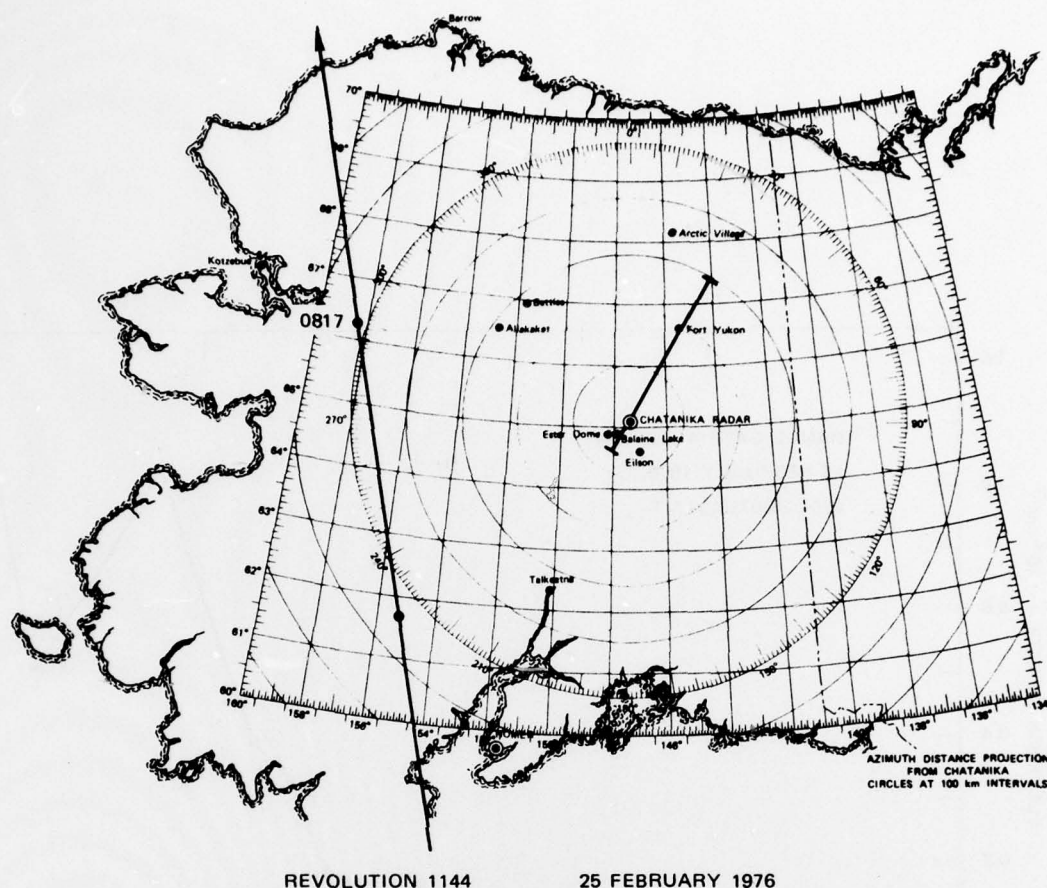


FIGURE 11 S3-2 GROUNDTRACK DURING REVOLUTION 1144 ON 25 FEBRUARY 1976. The latitudinal extent of E-region measurements at an altitude of 100 km is shown by the heavy solid line.

Prior to the S3-2 pass on 25 February 1976 the Chatanika radar was operated in a continuous scan between the geomagnetic zenith and the northern horizon. The E-region (100 km altitude) latitudinal extent of the scan limits is shown in Figure 11.

The latitudinal variation of the electron density and height-integrated conductivity measured during the elevation scan at the time of the S3-2 pass is shown in Figure 12. The main trough was overhead at Chatanika and the equatorward edge of the diffuse aurora was about 100 km north of Chatanika. Associated with the diffuse aurora boundary is a large gradient in ionospheric conductivity.

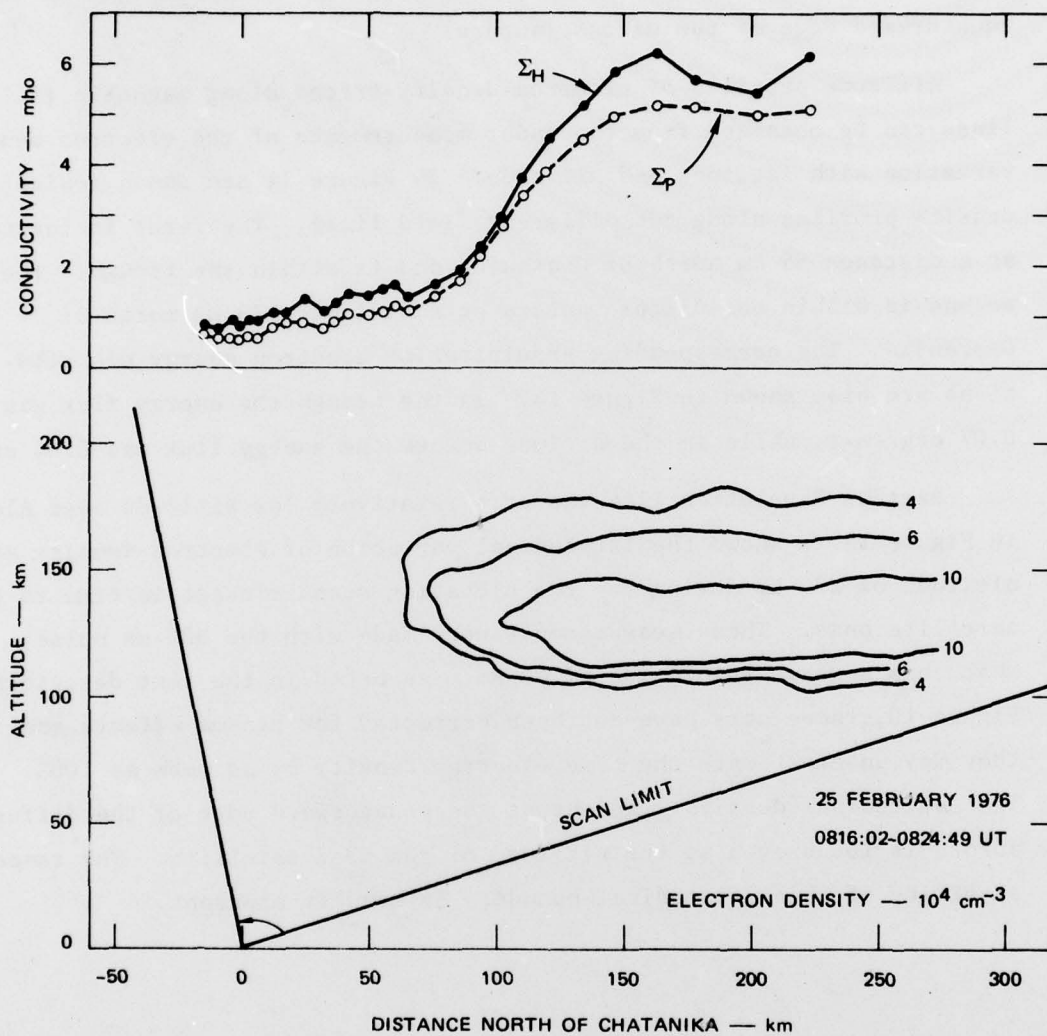


FIGURE 12 LATITUDINAL VARIATION OF IONIZATION AND CONDUCTIVITY MEASURED DURING THE ELEVATION SCAN BETWEEN 0816:02 AND 0824:49 UT ON 25 FEBRUARY 1976

The latitudinal variation of the ionospheric electric field and electric current during this scan are shown in Figure 13. Both the electric field and the electric current were directed to the northeast. There were large gradients in both components of the electrojet at the equatorward edge of the diffuse aurora.

Altitude profiles of electron density traced along magnetic field lines can be obtained from the radar measurements of the electron density variation with latitude and altitude. In Figure 14 are shown ionization density profiles along two different field lines. The first is located at a distance 55 km north of Chatanika and is within the trough. The second is within the diffuse aurora at a distance 179 km north of Chatanika. The corresponding precipitating electron energy distributions are also shown in Figure 14. In the trough the energy flux was 0.07 erg/cm-s, while in the diffuse aurora the energy flux was 0.84 erg/cm²-s.

Because Revolution 1144 was at a relatively low altitude over Alaska, in Figure 15 is shown the latitudinal variation of electron density at an altitude of 230 km during the two elevation scans closest in time to the satellite pass. These measurements were made with the 320- μ s pulse, which has a range resolution of 48 km. As noted in the text describing Figure 10, these data have not been corrected for plasma effects and they may underestimate the true electron density by as much as 100%. The latitudinal density gradient at the equatorward edge of the diffuse aurora is found even at the altitude of the S3-2 satellite. The temporal stability of this latitudinal boundary is readily apparent.

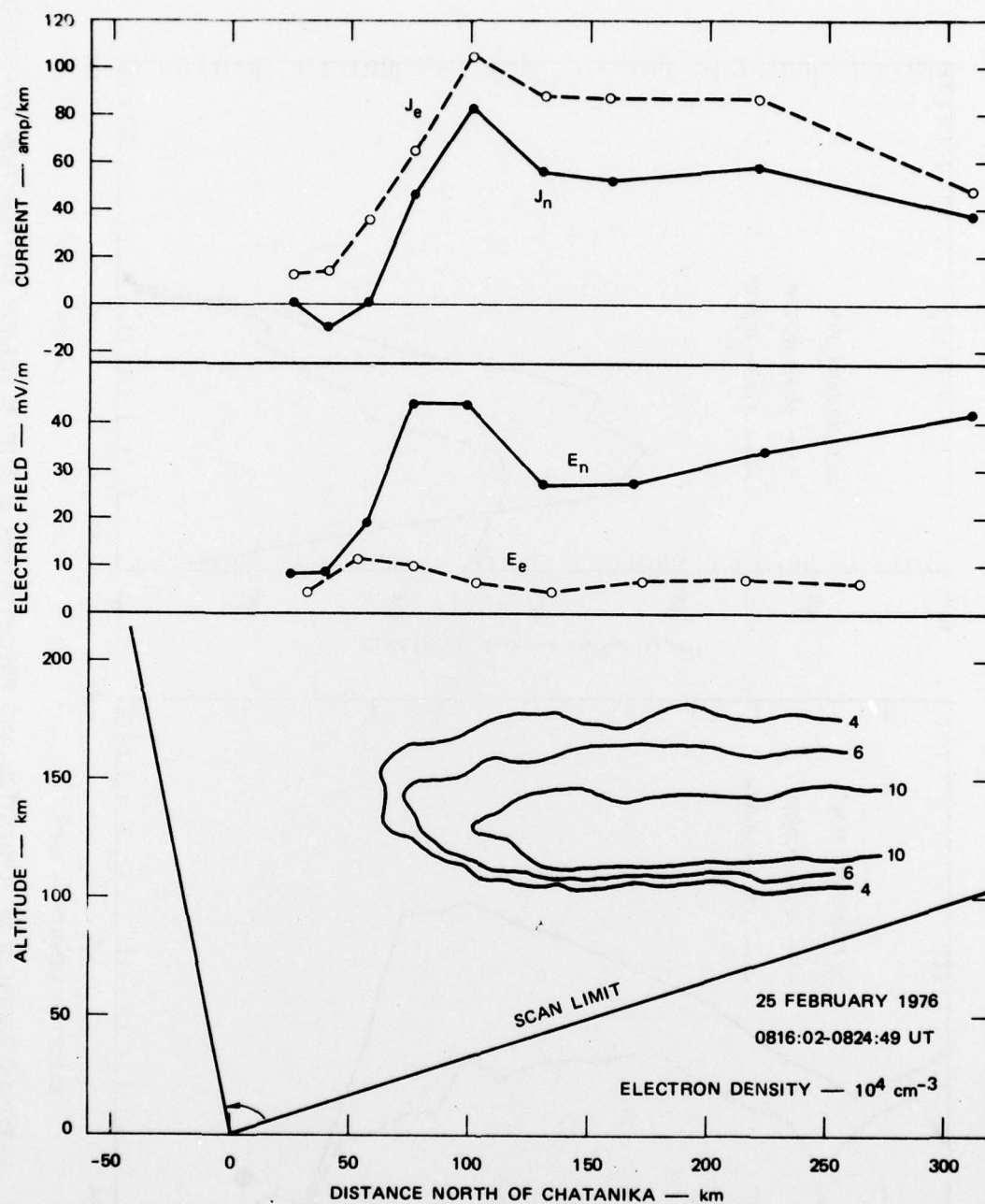


FIGURE 13 LATITUDINAL VARIATION OF ELECTRIC FIELD AND ELECTRIC CURRENT MEASURED DURING THE ELEVATION SCAN BETWEEN 0816:02 AND 0824:49 UT ON 25 FEBRUARY 1976

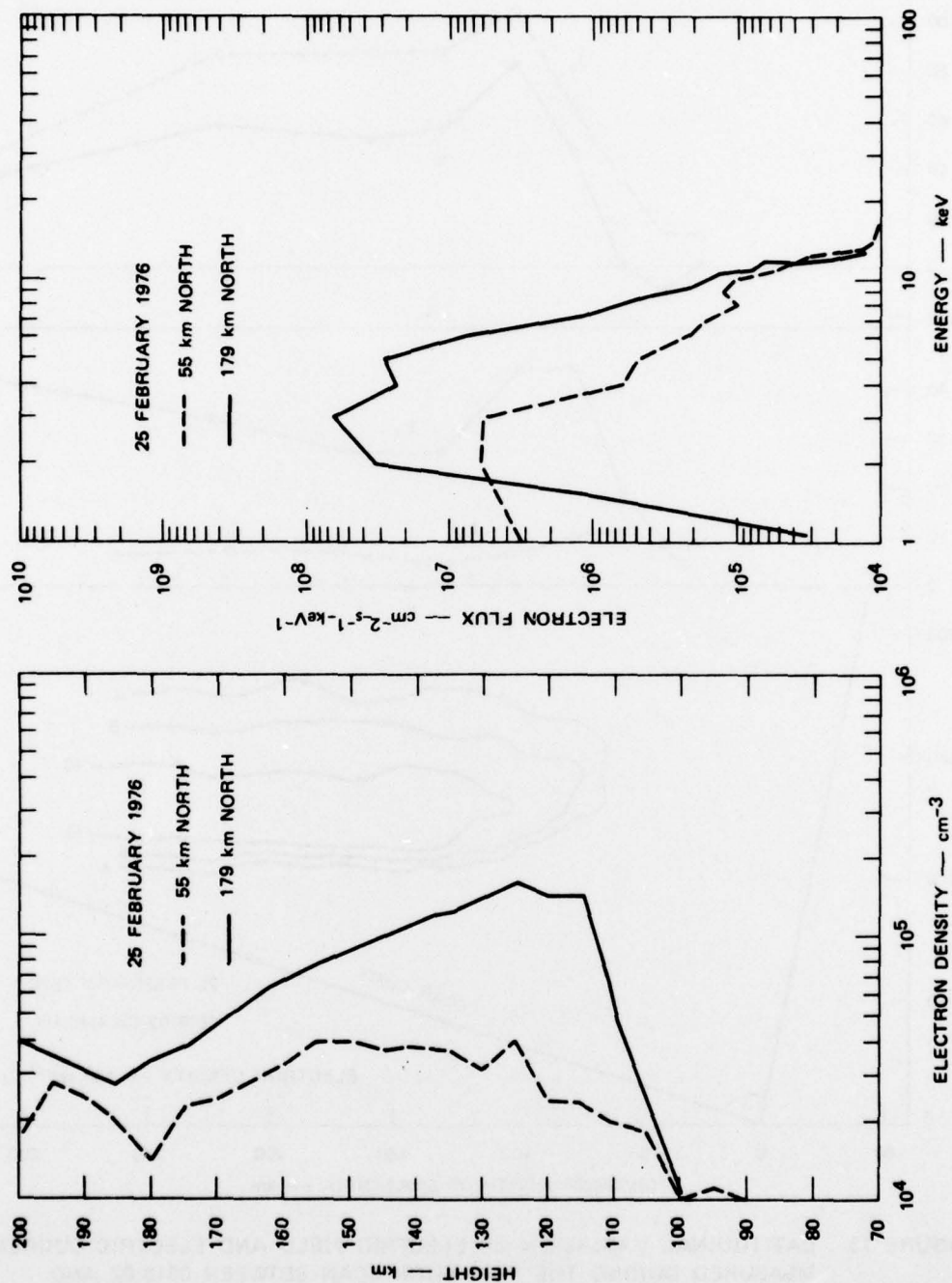


FIGURE 14 ALTITUDE PROFILES OF IONIZATION AND PRECIPITATING ELECTRON ENERGY DISTRIBUTION MEASURED ALONG TWO FIELD LINES DURING THE ELEVATION SCAN BETWEEN 0816:02 AND 0824:49 UT ON 25 FEBRUARY 1976

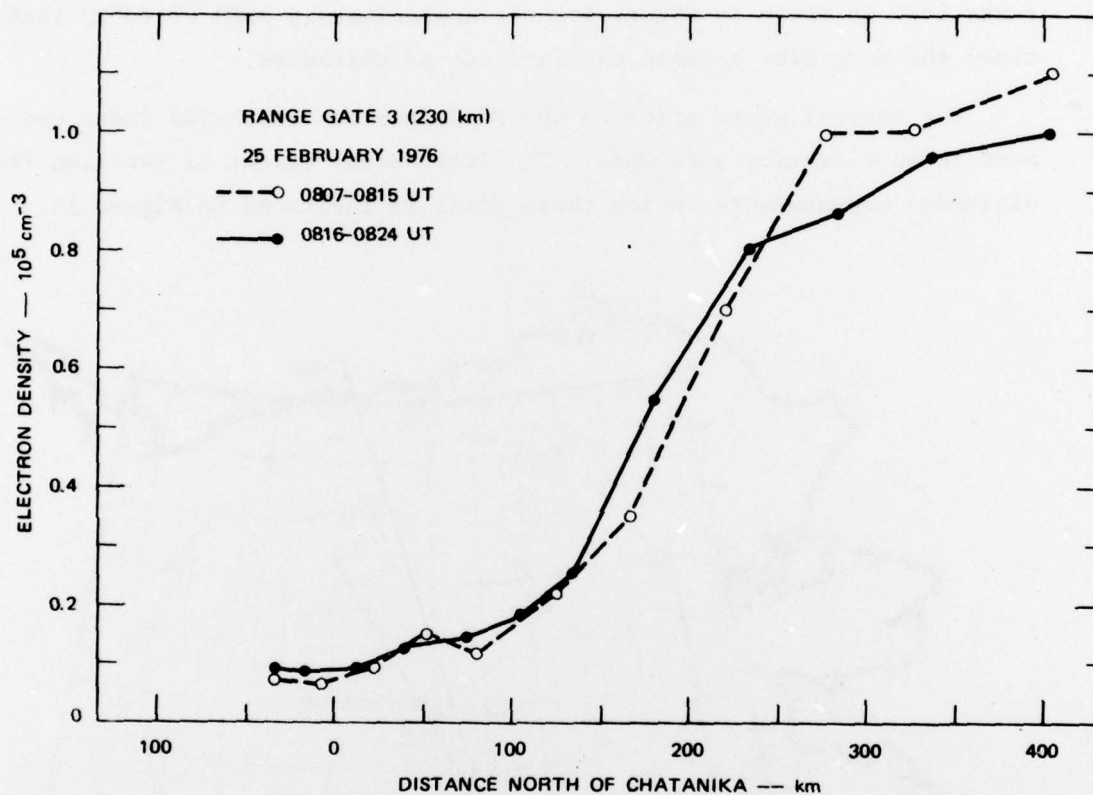


FIGURE 15 LATITUDINAL VARIATION OF ELECTRON DENSITY AT AN ALTITUDE OF 230 km DURING THE TIME ELEVATION SCANS CLOSEST TO THE S3-2 PASS ON 25 FEBRUARY 1976

4. MEASUREMENTS OF AN ACTIVE MORNING AURORA (REVOLUTION 6352 ON 24 FEBRUARY 1977)

The S3-2 groundtrack over Alaska during Revolution 6352 on 24 February 1977 is shown in Figure 16. At approximately 1509 UT (0509 local time) the satellite crossed the latitude of Chatanika.

For several hours prior to the S3-2 pass the Chatanika radar was operated in an elevation scan mode. The latitudinal extent of E-region (100 km altitude) measurements during these scans is indicated in Figure 16.

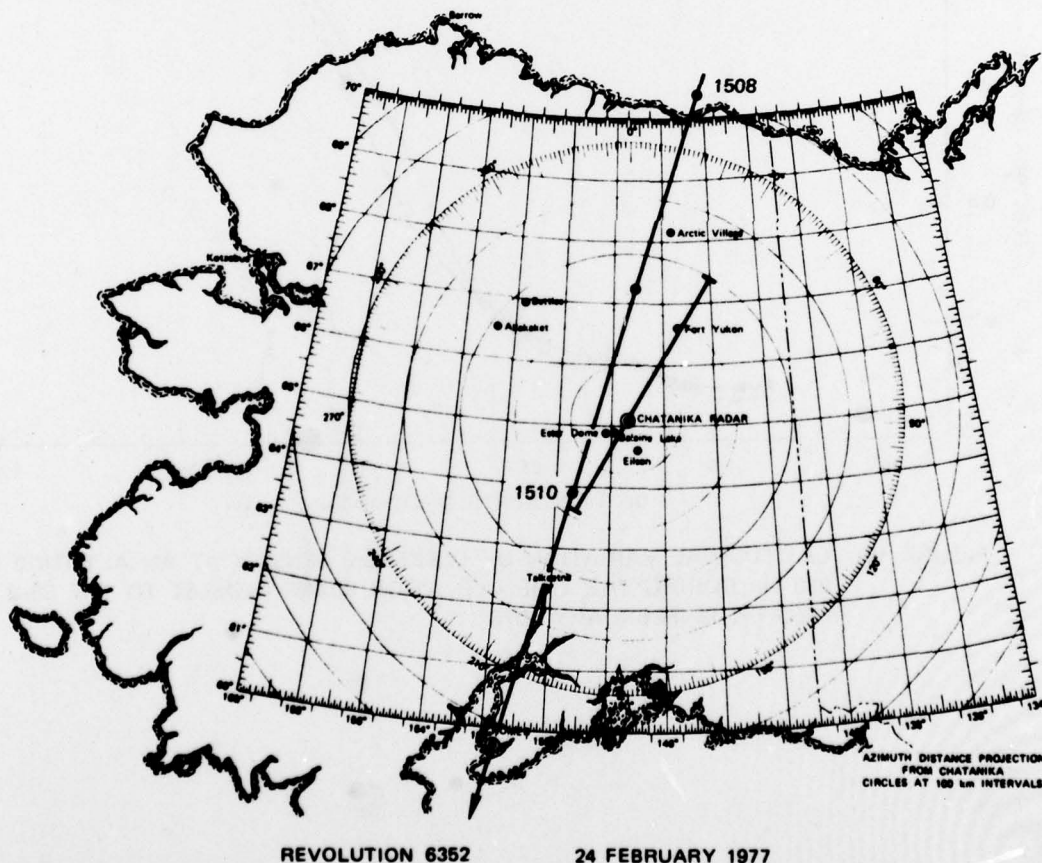


FIGURE 16 S3-2 GROUNDTRACK DURING REVOLUTION 6352 ON 24 FEBRUARY 1977. The latitudinal extent of E-region measurements at an altitude of 100 km is indicated by the heavy solid line.

The latitudinal variation of electron density and height-integrated conductivity measured between 1500:12 and 1515:25 UT are shown in Figure 17. The scan was interrupted between 1510:30 and 1514:05 UT by a radar equipment failure. Substantial ionization was evident over the entire region surveyed by the radar. A latitudinal gradient in ionization and conductivity was present overhead at Chatanika and a broad auroral band was located about 150 km north of Chatanika. The maximum electron density in the auroral band was about $5 \times 10^5/\text{cm}^3$.

The electric field and currents measured during this scan are shown in Figure 18. The gap in the measurements occurs near the geomagnetic zenith where it is not possible to measure horizontal ion velocities. Large spatial gradients are apparent in all components of the electric field and current. Overhead and to the nearby north the field was northeastward, with a rotation to the southwest occurring at the poleward edge of the auroral band. In the weaker ionization in the south the field was also directed to the southwest. The major horizontal currents present were a westward electrojet in the south and far north and an eastward electrojet in the more intense ionization overhead. The meridional current was generally northward and weaker than the eastward electrojet.

Altitude profiles of electron density and corresponding precipitating electron energy distributions along two field lines during this scan are shown in Figure 19. The first profile is along a field line 55 km south of Chatanika in the region of weaker ionization and the southward electric field. The second profile is at a distance 27 km north in the region of the northward electric field. The differential energy distributions at both locations have similar shapes, with more intense fluxes present in the region of greater ionization.

Preliminary values for S3-2 measurements of one component of the electric field were available for comparison with the Chatanika radar measurements. The spacecraft measurement available for this report is the magnitude of the electric field component along a direction oriented 10° east of south. The S3-2 measurements in the latitudinal region

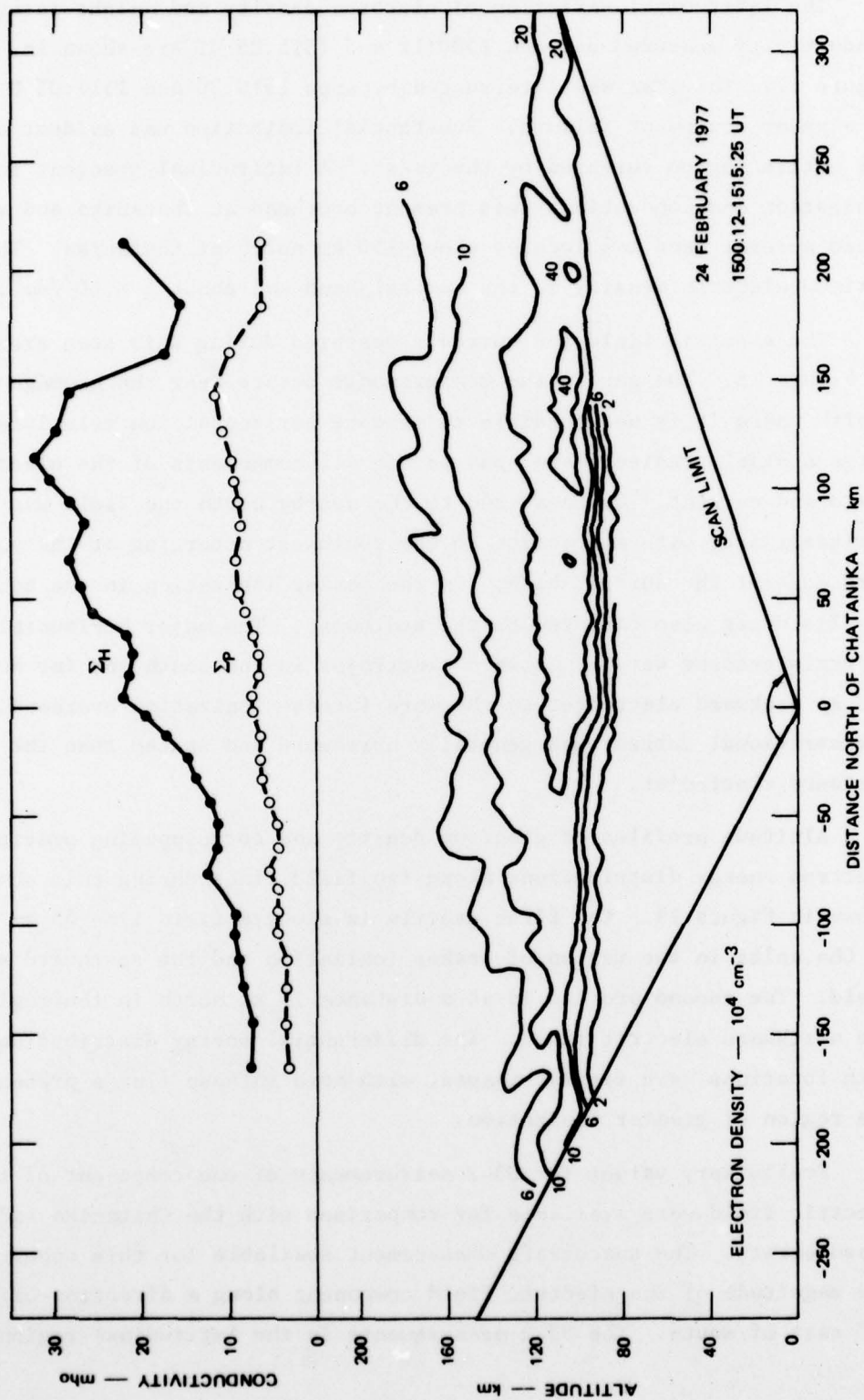


FIGURE 17 LATITUDINAL VARIATION OF IONIZATION AND CONDUCTIVITY MEASURED DURING THE ELEVATION SCAN BETWEEN 1500:12 AND 1515:25 UT ON 24 FEBRUARY 1977

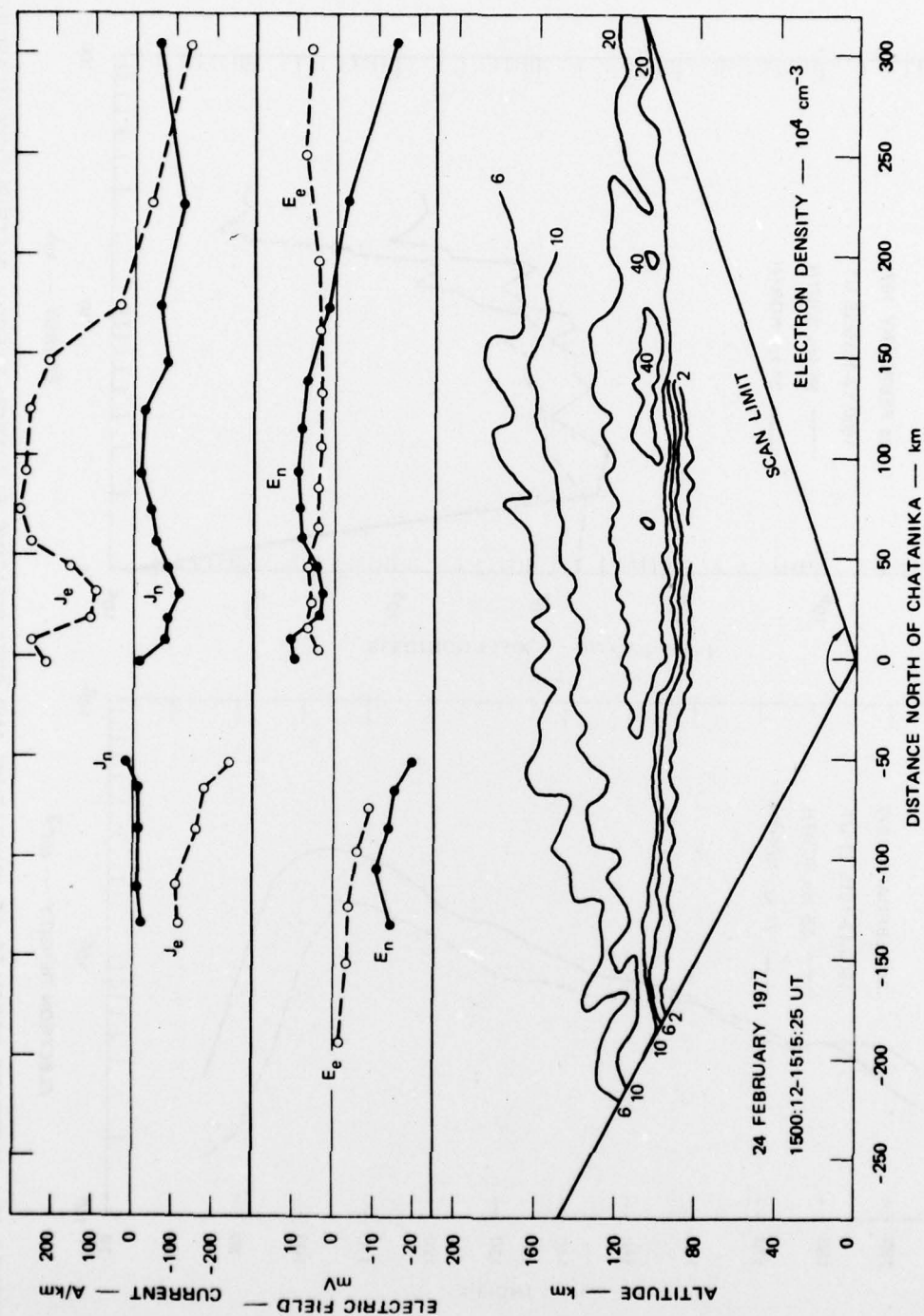


FIGURE 18 LATITUDINAL VARIATION OF ELECTRIC FIELD AND ELECTRIC CURRENT MEASURED DURING THE ELEVATION SCAN BETWEEN 1500:12 AND 1515:25 UT ON 24 FEBRUARY 1977

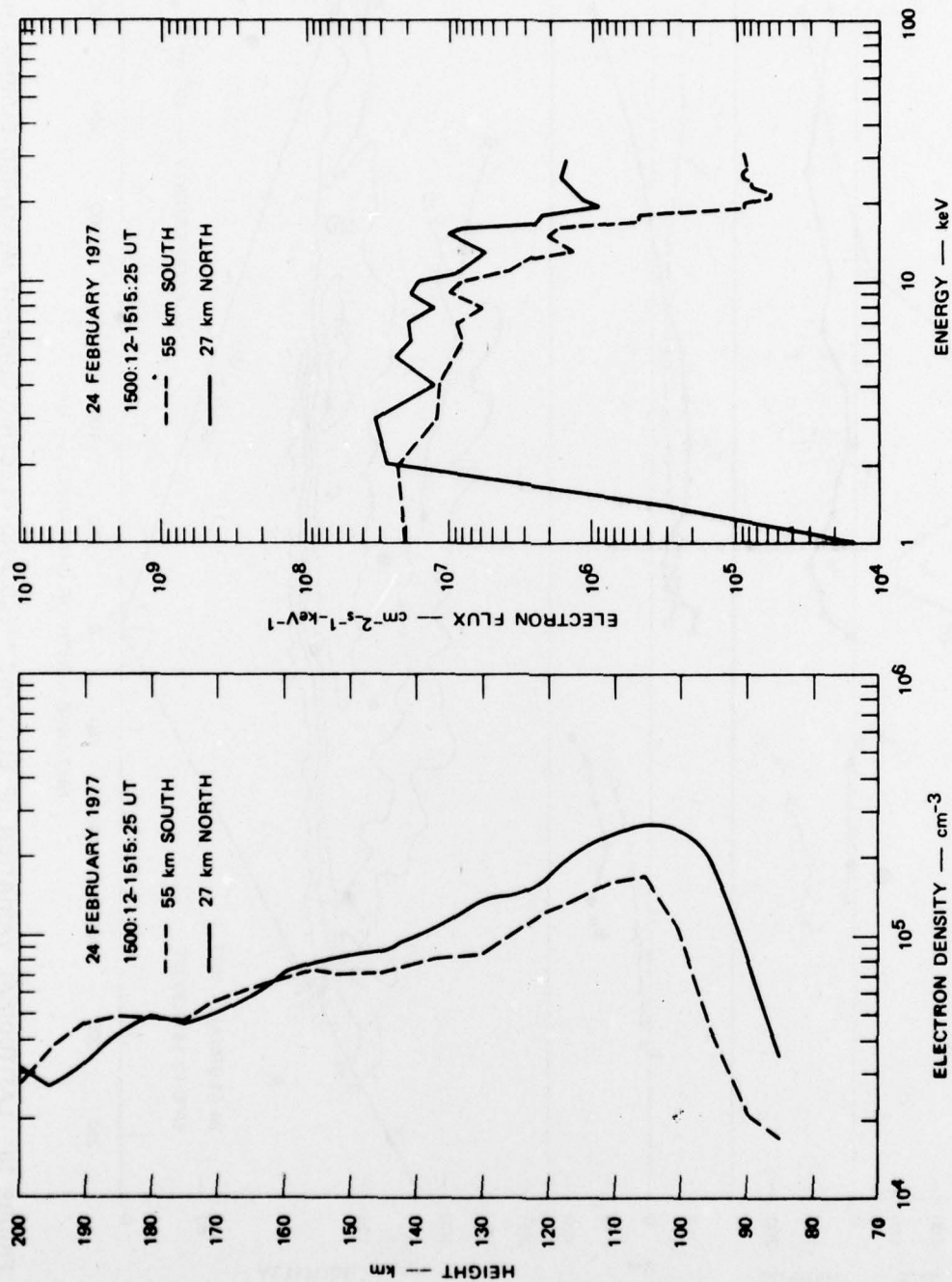


FIGURE 19 ALTITUDE PROFILES OF IONIZATION AND PRECIPITATING ELECTRON ENERGY DISTRIBUTION MEASURED ALONG TWO FIELD LINES DURING THE ELEVATION SCAN BETWEEN 1500:12 AND 1515:25 UT ON 24 FEBRUARY 1977

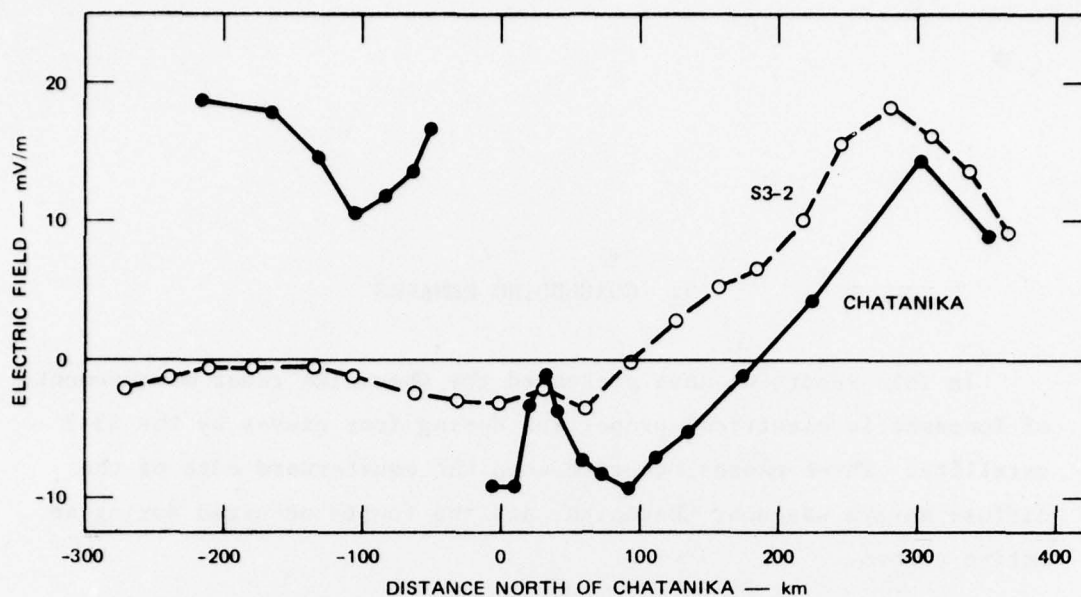


FIGURE 20 COMPARISON BETWEEN PRELIMINARY ELECTRIC FIELD MEASUREMENTS BY THE S3-2 SATELLITE AND MEASUREMENTS BY THE CHATANIKA RADAR. The electric field magnitude is of the component along a direction 10° east of south.

surveyed by the Chatanika radar are shown in Figure 20. Also shown is the magnitude of the same component derived from the Chatanika vector electric field measurement. Differences and similarities between the two measurements are readily apparent. South of Chatanika the two measurements disagree both in magnitude and direction. North of Chatanika both techniques would show excellent agreement in magnitude and direction if there was either an 80-km shift in the location of the two measurements or a 6 mV/m offset in one of the measurements. In this region there is a remarkable agreement in the latitudinal electric field gradient measured by the two instruments. When final values for the vector electric field are supplied by the S3-2 experimenters, it will be possible to make a definitive comparison of the two data sets.

5. CONCLUDING REMARKS

In this report we have presented the Chatanika radar measurements of ionospheric electrical properties during four passes by the S3-2 satellite. Three passes occurred when the equatorward edge of the diffuse aurora was near Chatanika, and the fourth occurred during an active aurora.

Ionospheric parameters measured by the radar include the electron density, conductivity, electric field, electric current, and energy distribution of precipitating electrons. When the final S3-2 spacecraft data become available, it will be possible to combine the radar and satellite measurements to interpret the ionospheric and auroral phenomena present during these passes.

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